BNL-71594-2003-CP

Prepared for the 42nd
IUPAC General Assembly
in Ottawa, Canada
August 8th - 17th, 2003

STATUS OF RADIOACTIVE ELEMENTS IN THE ATOMIC WEIGHTS TABLE

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I. Introduction

During discussions within the Inorganic Chemistry Division Committee, that dealt with the Periodic Table of the Chemical Elements and the official IUPAC position on its presentation, the following question was raised. When the various chemical elements are presented, each with their appropriate atomic weight value, how should the radioactive elements be presented? The Atomic Weights Commission has treated this question in a number of different ways during the past century, almost in a random manner. This report reviews the position that the Commission has taken as a function of time, as a prelude to a discussion in Ottawa about how the Commission should resolve this question for the future.

II. Historical Treatment

The treatment of the radioactive elements (both naturally occurring and synthetic) in the Atomic Weights Table of the IUPAC's Commission on Atomic Weights has been extremely variable over the past century. The Commission has oscillated back and forth between including an entry of an atomic weight value or a mass number for these elements or for just some of these elements and eliminating some or all of the entries from the Table and only listing the name and chemical symbol with no corresponding value. I have attempted to summarize these changes as a function of time, as noted in the various annual or biennial Reports of the Commission on Atomic Weights for the particular years that are indicated.

In the Report for the first International Atomic Weights Table, thorium was listed as Th = 232.5 and radium as Ra = 225, both values given on the oxygen = 16 scale.

In the 1909 Report, radium was changed in the Table to Ra = 226.4 and thorium to Th = 232.42.

In the 1911 Report, thorium was changed to Th = 232.4.

In the 1912 Report, niton (also called radium emanation) was introduced with the atomic weight value of Nt = 222.4.

In the 1916 Report, the radium value was changed to Ra = 226.0.

In the 1919 Report, the thorium value was changed to Th = 232.15.

In the 1925 Report, the name niton and symbol Nt was changed to radon with the symbol Rn and the value was changed to Rn = 222. The radium value was changed to Ra = 225.95.

In the 1932 Report, thorium was changed to 232.12.

In the 1936 Report, protactinium was introduced with a value of Pa = 231 and radium was changed to Ra = 226.05.

In the 1947 Report, these four elements were still reported with the values: Pa = 231; Rn = 222; Ra = 226.05; and Th = 232.12.

In the 1949 Report, the Commission decided to add a series of new elements to the Table. These entries included relatively rare naturally radioactive elements, elements which had previously been reported but had been disputed (where the dispute was resolved by the IUPAC Inorganic Chemistry Division) and also some recently discovered elements. Since these elements are produced in the laboratory and not discovered in nature, the atomic weight of these artificial products will depend on the production method. Since atomic weight is a property of an element as it occurs in nature, it would be incorrect to assign an atomic weight value to that element. As a result of this discussion, the Commission decided to provide only the mass number of the most stable (longest-lived) known isotope as the number associated with these entries in the Atomic Weights Table. Four entries for 1947 were now accompanied by: Ac = 227; Am = 241; At = 210; Cm = 242; Fr = 223; Np = 237; Pu = 239; Po = 210; Pm = 147; and Tc = 99.

In the 1951 Report, Bk = 245 and Cf = 246 were added to the previous list of radioactive elements, where there were the following mass number changes: Am = 243; Cm = 243; Pu = 242; and Pm = 145. In addition, a range was added for the first time for element S = 32.066 ± 0.003.

In the 1953 Report, the following mass number changes were noted: Cf = 248; Cm = 245; and the thorium atomic weight value was changed to Th = 232.05.

In the 1955 Report, there was one addition, Mv = 256; and two changes Bk = 249 and Cf = 249.

In the 1957 Report, the Commission noted that they had adopted the practice of including mass numbers of selected isotopes of radioactive elements that are either too short-lived or had too variable an isotopic composition to justify the assignment of atomic weight values. Now the Commission decided to discontinue this practice on the grounds that the kind of information supplied by the mass number is inconsistent with the primary purpose of a Table of Atomic Weights, i.e., to provide accurate values of "these constants" for use in chemical calculations. This change in policy omits the mass number for radioactive elements, whether naturally occurring or synthetic. Exceptions would be made for two naturally occurring elements, U and Th, and certain other elements that are only slightly radioactive.

In addition, for the first time an auxiliary Table of Radioactive Elements would be included in the Report, where the entry would be the isotope of that element which had the longest known half-life. There were two chemical symbol changes made. Argon's symbol A became Ar and mendelevium's symbol Mv became Md. All of the previous entries with mass numbers were replaced with a blank in the atomic weight column. In addition, three new elements were added, also with blank entries, Es, Fm and No.

In the 1961 Report, all of the entires were the same but Th was changed to 232.038. Ranges were added for H, B, C, O, Si and S to account for natural variation and ranges added for Cl, Cr, Fe, Br and Ag to account for experimental uncertainties.

In the 1967 Report, Lw was added with a blank entry and the Table remained the same otherwise.

In the 1969 Report, uncertainties were added for all elements for the first time. For four elements, which were considered to be technologically important in the form of a single nuclidic species, the atomic weight value of the most commonly available long-lived nuclide was added. These four were Np = 237.0482; Pa = 231.0359; Ra = 226.0254; and Tc = 98.9062. Footnotes indicated that Ra, Th and Pa were mononuclidic elements and Np was considered to have only one predominant isotope.

In the 1971 Report, the value for Tc was removed from the Table because ^{97}Tc was becoming available as well as ^{99}Tc. The footnote that Np was considered to have only one predominant isotope was removed.

In the 1973 Report, The Commission noted that it had abandoned the use of mass numbers for the following reasons:
1) the use of the mass number was too imprecise to be useful for much analytical work.
2) users knew their source so they would have the best useable knowledge of the applicable atomic weight value.
3) many mass numbers would have changed because of changes in the longest half-life of a radioactive element's isotopes. In recent years, ^{255}No would have been replaced by ^{259}No and ^{256}Lr would have been replaced by ^{260}Lr.
4) the isotope with the longest half-life is not the one which is most widely available, e.g., Tc, Pu and Cf.
However, since Table users were dissatisfied with the omission of values in the Table for well known elements, it was decided to reintroduce the mass numbers for these elements. There were 17 elements in this category in the Table.

In the 1975 Report, five radioactive elements were listed with an Atomic Weight of the longest-lived radioisotope of that element including, Ac = 227.0278, as well as Np, Pa, Ra and Th. This reduced the list of radioactive elements given with only a mass number to 16.

In 1973, the Commission on Nomenclature of Inorganic Chemistry (II.2) proposed a systematic nomenclature for the heavy elements, i.e., with Z > 100, which was a mixture of Latin and Greek roots. This systematic naming scheme was officially published by IUPAC in December 1976.

In the 1977 Report, elements number 104, 105 and 106 were added to the Table with their IUPAC systematic names and three letter symbols and a mass number. The brought to 19 the number of elements listed with only mass numbers. Ra, Ac Th, Pa and Np continued to be in the Table with an Atomic Weight value. The mass number for Tc was changed from 97 to 98 and the mass number for Es was changed from 254 to 252.

In the 1983 Report, element 107 was added to the Table. It was decided that Th was an element with a well defined (mononuclidic) composition in minerals with only rare exceptions. It would continue to be listed with an atomic weight value. The remaining radioactive elements were considered to lack a characteristic terrestrial isotopic composition from which an atomic weight value could be calculated to five or more figure accuracy, without prior knowledge of the sample. It was thought that a standard atomic weight value has little meaning for these elements. There was also no general agreement on which of the isotopes of the radioactive element is, or is likely to be "important. These twenty-four elements were listed in the Table with no further information, i.e., no mass number or atomic weight value.

In the 1985 Report, the Commission decided that since ^{233}Pa had not been proven to be a naturally occurring radionuclide as a decay product of ^{237}Np, protactinium would now be treated as a so-called "psuedo-mononuclidic element" for the purposes of tabulating an atomic weight. The list of radioactive elements with blank entries in the Table was now reduced to twenty three elements.

In the 1987 Report, the Commission discussed the concept of mononuclidic elements (elements with no isotopes, i.e., only one stable nuclide). Using a criterion of a half-lfe of $3 \cdot 10^{10}$ years as the determining factor for stability, thorium and protactinium were excluded from being considered as mononuclidic elements. Thorium was considered to exhibit a range of characteristic terrestrial isotopic compositions of long-lived radio-nuclides such that a meaningful atomic weight could be given in the Table.
Protactinium was not considered to meet this criterion and was listed in the Table with a blank entry, bringing the total number of such radioactive elements to twenty four again.

In the 1989 Report, the Commission decided that protactinium once again met the criterion of having a characteristic terrestrial isotopic composition and a tabulated atomic weight value in the Table. The number of radioactive elements with a blank entry dropped to twenty three elements again.

In the 1991 Report, elements 108 and 109 were added to the Table bringing the number of radioactive elements with a blank entry to twenty five elements.

In the 1995 Report, elements 110 and 111 were added to the Table and there were now twenty seven radioactive elements with blank entries in the Table.

In the 1997 Report, element 112 was added to the Table and there were twenty eight radioactive elements with blank entries in the Table.

In the 1999 Report, elements 114, 116 and 118 were added to the Table and there were now thirty one radioactive elements with blank entries in the Table.

In the 2001 Report, element 118 was removed from the Table when it was determined to have been based on fabricated data and the authors withdrew their claim of discovery for this element. The number of radioactive elements with blank entries in the Atomic Weights Table was reduced to thirty elements.

III. Conclusions

In the past, the Commission has made decisions on how to treat the Radioactive Elements in the Table at each General Assembly meeting without a thorough review of all of the Commission's past actions on the subject. It would be appropriate to ask the Commission to review this status once again in Ottawa, since this could well be the final meeting of the Commission and the last chance for the Commission to voice an opinion on the status of the radioactive elements in the Atomic Weights Table.

IV. Acknowledgements

This research was supported in part by the United States Department of Energy (USDOE) under the contract DE-AC02-98CH10886.